Art. XLII.—*The Genus* Cordyceps *in New Zealand.*

By G. H. Cunningham.

With Special Entomological Notes on the Hosts, by J. G. Myers.

[*Read before the Wellington Philosophical Society, 27th October, 1920; received by Editor, 31st December, 1920; issued separately, 8th August, 1921.*]

Plates LIX–LXII.

In the genus *Cordyceps* are included those fungi which produce the so-called "vegetable caterpillars," "vegetable wasps," &c., which are insects that have been attacked by fungi and their tissues replaced by the vegetative portion of the attacking fungus.

In writings of about a century ago the various species of *Cordyceps* were supposed to be insects changing into plants. To quote one example, an author (25) in 1763, describing *Cordyceps sobolifera* Tul., which he called the "vegetable fly," states, "In the month of May it buries itself in the earth and begins to vegetate. By the latter end of July the tree arrives at its full growth and resembles a coral branch, and is about three inches high, and bears several little pods which, dropping off, become worms, and from thence flies, like the English caterpillar."

Naturally, the earlier systematists had some difficulty in placing such peculiar fungi. Species of this genus were first included under *Clavaria* (12), a Basidiomycete; they were then transferred to *Sphaeria* (19), a genus which at that time covered all the genera now included in the Pyrenomycetes; thence to *Cordyceps* by Link (11); from this to *Torrubia** by Tulasne; and, as this latter genus was not tenable, back to *Cordyceps*.

For the most part, the species of *Cordyceps* grow on insects, but two—*C. capitata* (Holmsk.) Link, and *C. ophioglossoides* (Ehr.) Link—grow on subterranean fungi, *Elaphomyces* spp. *C. ophioglossoides* has recently been recorded growing on a locust in Japan (15).

Distribution.

The genus *Cordyceps* is widely distributed, being found in Britain, Europe, North and South America, China, Ceylon, Japan, Australia, and New Zealand. Many species are extremely limited in their distribution, while others again are more or less cosmopolitan: *e.g.*, *Cordyceps gracilis* Grev. has been recorded from Britain, Europe, North America, Algeria, Australia, and, doubtfully, from New Zealand (as *Cordyceps entomorrhiza* (Dicks.) Link).

Biology.

Little is known of the life-history of *Cordyceps*. Tulasne (21) and de Bary (1) have worked out the life-history of the common European species, *C. militaris* (L.) Link. Their investigations tend to show that a spore, on coming in contact with a host, germinates and produces a germ-tube which penetrates the cuticle and body-wall. Inside the body-cavity this germ-tube branches, forming hyphae, which penetrate to all parts of the body. In the blood gemmae are produced: these are cells asexually produced from the ends of hyphae. They are exceedingly small, and are

* The genus *Cordyceps* of Link was by Tulasne (22) divided into two genera: (1) *Torrubia*, because of the presence of two spore-forms in the life-cycle; and (2) *Cordylia*, embracing all forms growing on subterranean fungi.

rapidly carried in the blood-stream to different parts of the body, where they in turn give rise to hyphae. In this manner the fungus rapidly spreads and quickly kills the host.

Infection of the host may occur from the germ-tube from an ascospore, or from hyphae developed from conidia borne by the Isarial form of *Cordyceps*. A conidium may germinate, and the subsequent hyphae live saprophytically on decaying wood or other organic matter for some considerable time. These hyphae on coming in contact with a host are capable of entering the host-tissues. In the decaying wood from which *Cordyceps Aemonae* Lloyd was taken, mycelial development was so pronounced as to be visible to the naked eye. The writer carried out some rough experiments to ascertain whether this mycelium was capable of attacking the larvae of *Aemona hirta* Fabr., the host of *C. Aemonae*. Healthy host larvae (quiescent) were obtained from rotting logs in which no sign of *Cordyceps* was found, and were buried in pots filled with sterilized sawdust in which were mixed fragments of infected wood taken from the centre of the log that contained *C. Aemonae*. The pots were kept moist and covered with bell jars. In two months' time these larvae were exhumed, and were all found to be dead and surrounded by hyphae. They were replaced, and in three months stromata bearing the Isarial stage of *C. Aemonae* appeared above the surface of the sawdust. Unfortunately this experiment was not carried further to determine whether the perithecial stage could be obtained; but at the time of the first experiment Isarial forms of *C. Aemonae* were brought into the laboratory from logs in the forest in which they were found, and were buried in sawdust with the stromata alone showing. The pots were kept moist and covered; in three months immature perithecia had appeared on one or two of the stromata. (Plate LIX, fig. 1, *b*). The sawdust used in these experiments was obtained by sawing up dead, sound, dry logs of mahoe (*Melicytus ramiflorus* Forst.).

In the host the hyphae continue to develop until finally the whole of the internal tissues are replaced by the mycelium of the fungus, when it forms a hard, compact mass, the cuticle and sometimes portions of the alimentary system alone remaining unaltered. (Plate LXI, fig. 2.) This mycelial mass is known as a sclerotium; from it, usually after a period of rest, the stromata bearing the fructifications of the fungus arise. The stromata vary considerably in shape, size, and number, according to the nature and habitat of the host. If the host is subterranean, then the stromata will necessarily have to be long enough to rise to the surface of the ground, so the length would be governed by the depth of the host. Again, if the host is exposed, as in the case of *Cordyceps clavulata* (Schw.) Ellis & Ev.,* the stromata would necessarily be short.

In some species there are two kinds of fructification: the first is known as the Isarial form, and bears conidia; the second form, which appears after the Isarial (when the latter is present), bears the ascospores. Conidia are simple, short-lived spores, and are abjointed in immense numbers from the ends of hyphae. They may be borne on a stroma, in which case they are abjointed from the terminals of the hyphae forming the stroma, or may occur on the terminals of hyphae which form a loose covering over the external surface of the host. The relationship between this Isarial and the later (or *Cordyceps*) stage is known in a few species only, and in the majority of cases is assumed merely on account of the occurrence of both forms from the same host. As mentioned above, *Isaria* is capable of

* This species occurs on various species of *Lecanium*.

living as a saprophyte ; *Isaria*-like forms also occur as the conidial stages in the life-cycle of *Xylaria*, the species of which are saprophytes, occurring on dead logs, grass, &c. The ascospores of *Cordyceps* are filiform, multicellular bodies borne in asci (cylindrical sacs), which in turn are enclosed in perithecia (variously shaped receptacles bearing asci on their inner walls). The perithecia are, as a rule, densely packed on the surface of or embedded in the substance of the stroma. Each is provided with a definite opening (ostiole) through which the spores escape at maturity. Each ascus bears a small cap on its distal end, pierced by a minute pore. The ascospores are filiform, and lie closely packed in parallel fascicles, eight in each ascus; they are at first continuous, but when mature are divided by many transverse septa—a hundred or more. Eventually they break up at these septa into secondary spores. Each secondary spore is capable of germinating and infecting a host. From this it is obvious in what enormous numbers these spores are produced. Assuming a stroma to bear 100 perithecia, each perithecium to contain 100 asci, and each ascospore to break up into 100 secondary spores, the number of ascospores produced would total 8,000,000 —and this is, of course, a very modest estimate of the actual contents of each perithecium, ascus, &c.: for example, a large specimen of *Cordyceps Robertsii* Hook. contains many thousands of perithecia.

Distribution of Spores.

Conidia are light, minute bodies borne on the ends of hyphae, and are thus admirably adapted for wind distribution. Ascospores, being enclosed in perithecia, are primarily dependent on other means of distribution. If a mature perithecium be placed in water, in an hour or so enormous numbers of asci are seen to be collected outside the ostiolum. They have been forced out of the perithecium by the swelling of certain hyphal tissue at the base of the asci. No doubt in nature a similar condition exists: here the spores are forced out and remain on the exterior of the perithecia, or are washed on to the ground, leaves, logs, &c., and when dry may be carried by wind, insects, or other agency to some distance from their source.

Technical Description of the Species.

Although a large number of species have been described, five only are definitely known to occur in New Zealand; of these, four are endemic, and one occurs also in Australia and Tasmania.

Cordyceps* (Fries) Link, *Handbk.*, vol. 3, p. 347, 1833 (emended).

Sphaeria § *Cordyceps* Fries, *Syst. Myc.*, vol. 2, p. 323, 1823; *Torrubia* Lév. Tulasne in *Fung. Carp.*, vol. 3, p. 5, 1865.

Stromata† arising from a sclerotium composed of mycelial tissue within the bodies of insects (rarely in other fungi), simple or branched ; sterile below, fertile on upper portion.

Perithecia immersed or superficial, seated on or in fertile portion of stroma ; spherical, oval, flask-shaped, &c. ; ostiolate.

Asci cylindric, 8-spored, hyaline, distal end capitate ; paraphyses absent.

* The name *Cordyceps* was first used by Fries as the name of a tribe of the Pyrenomycetes, including the genera *Cordyceps* and *Xylaria*. *Torrubia* was first used by Léveillé in manuscript in the Paris Museum Herbarium, and was later adopted by Tulasne (*l.c.*).

† Stromata : This term is used very loosely by the various mycologists who have worked on this genus ; as here used it includes both fertile and sterile portions of the clubs.

Spores hyaline, filiform, multiseptate, arranged in the asci in parallel fascicles, or interwoven ; breaking up in the asci into secondary spores, or remaining entire.

Isarial stage when present forming an effused downy weft or an erect simple or variously branched stroma, consisting of hyphae bearing the hyaline continuous conidia on their apices.

1. Cordyceps Sinclairii Berk., *Fl. N.Z.*, vol. 2, p. 338, 1855. (Plate LXII, fig. 2.)

Sphaeria Basili Taylor, *N.Z. and its Inhabitants*, p. 424, 1844. *Torrubia caespitosa* Tulasne, *Select. Fung. Carp.*, vol. 3, p. 11, 1865. *Cordyceps caespitosa* Sacc., *Syll.*, vol. 2, p. 565, 1883.

Isarial Stage: Stromata growing from head of host, yellowish, from 18 mm. to 25 mm. high ; stems cylindrical, slender, simple or forked, sometimes confluent, 8 mm. or more high, divided above into numerous more or less cylindrical simple or slightly-lobed heads, which are sometimes disposed into a flabelliform mass clothed with innumerable oblong conidia 7-8 μ long. (Berkeley.)

Perithecia unknown.

Hosts.—*Melampsalta cingulata* Fabr. ; *M. cruentata* Fabr. (Plate LXII, fig. 3.)

Type Locality.—Tauranga, Poverty Bay, in loose gravelly soil in garden of Bishop Williams ; "growing from larva of some orthopterous [*sic*] insect."

Distribution.—Tauranga (Colenso) ; Farewell Spit, Nelson (Benham) (2) ; Weraroa (E. H. Atkinson) ! Hokitika (unknown collector) !

There is a fine specimen in the Canterbury Museum collection ! (Plate LXII, fig. 2, *c*).

No. 79, Biol. Lab. Herb. (Crypt.), Wellington.

This form should really have been named as an *Isaria*, as only he conidial form is known. It is possible that this may be the conidial stage of *Cordyceps sobolifera* Tul., as this species occurs on cicada in Japan. As all the other species occurring in New Zealand are endemic, with the exception of *Cordyceps Robertsii*, which is found only in Australia and New Zealand, it is, however, more likely that *Cordyceps* (?) *Sinclairii* is also endemic.

It is a very variable form, and assumes many different shapes. The colour of the stroma ranges from white in the most immature specimens, through yellow (colour mentioned by Berkeley), light brown, in more mature forms becoming pink, deepening in colour with age.

Although specimens are fairly plentiful in the New Zealand museums, none are known in any of the mycological collections abroad (14). A most interesting account of this species (with plate) is given by Benham (2).

Notes on the Hosts (by J. G. Myers).—Of the four specimens available for study, only two are in at all a good state from an entomological point of view ; but it is significant that all four hosts are nymphs of the final instar, with wing-pads well developed and the whole appearance suggestive of almost immediate emergence. This is of interest in that it is an indication that the nymphs are, of course, full-grown—a fact which enables an estimate of their species to be made with greater accuracy than would otherwise be possible. The two large specimens can be assigned almost certainly to *Melampsalta cingulata* Fabr. (6), while the two others, both of the same size and smaller than the other two, belong to one of the smaller cicadas, most probably to *Melampsalta cruentata* Fabr. (6).

2. Cordyceps Craigii Lloyd, *Myc. Notes*, p. 527, f. 718, 1911 (emended). (Plate LX, fig, 3; and text-figs. 1, 2.)

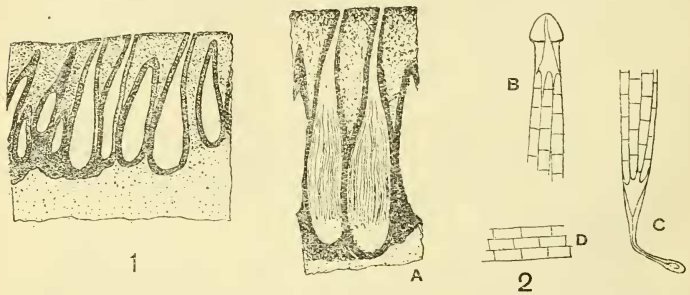
Isarial stage unknown.

Stroma solitary, 5–7 cm. long; growing from head of host; stem 3–4 mm. thick, 3–4 cm. long; fertile portion brown when fresh, blackening with age, flattened, falcate, 2–3 cm. long, 8–10 mm. wide, 3–4 mm. thick; surface smooth, or punctate with ostioles of perithecia.

Perithecia completely immersed, densely packed in stroma, flask-shaped, with long slender slightly curved necks; up to 1,500 μ long, 300–500 μ wide; walls 35 μ thick.

Asci hyaline, narrowly cylindrical, tapering slightly towards distal end, markedly towards proximal end, terminating in a long slender pedicel, not constricted below cap; 250–330 × 6–7 μ.

Spores in parallel fascicles in asci, same thickness throughout, ends bluntly pointed, 180–260 × 2 μ; secondary spores 3–4 × 2 μ; readily separable in asci.



[*Drawn by E. H. Atkinson.*

Cordyceps Craigii Lloyd.

Fig. 1.—Transverse section through fertile portion of stroma.
Fig. 2.—A. Perithecia (enlarged). B. Capitate apex of ascus. C. Base of ascus. D. Secondary spores, 3–4 × 2 μ.

Host.—Porina enysii Butl.; growing from head. (Plate LX, fig. 2.)

Type Locality.—Old and abandoned kumara (*Ipomoea batatas* Poir) beds, Auckland.

Distribution.—Auckland (E. Craig); Wellington, in ground under a karaka (*Corynocarpus laevigata* Forst.), in forest, vicinity of Wireless Hill (unknown collector)!

No. 192, Biol. Lab. Herb. (Crypt.), Wellington.

"Mr. Craig also sends two specimens collected in the bush which are very similar and probably the same species. I could not say positively, however, from the specimens, as they are both immature." (Lloyd.)

Specimen 192 was given me by Mr. H. Hamilton, of the Dominion Museum. He obtained it from a man who dug it up in the forest under a karaka.

Note on the Host (by J. G. Myers).—As this species has so far been recorded only from the North Island, the host, taking its size into consideration, is almost certainly *Porina enysii* Butl. (1), the larva of which, in the North Island, is the victim also of *Cordyceps Robertsii* Hook.

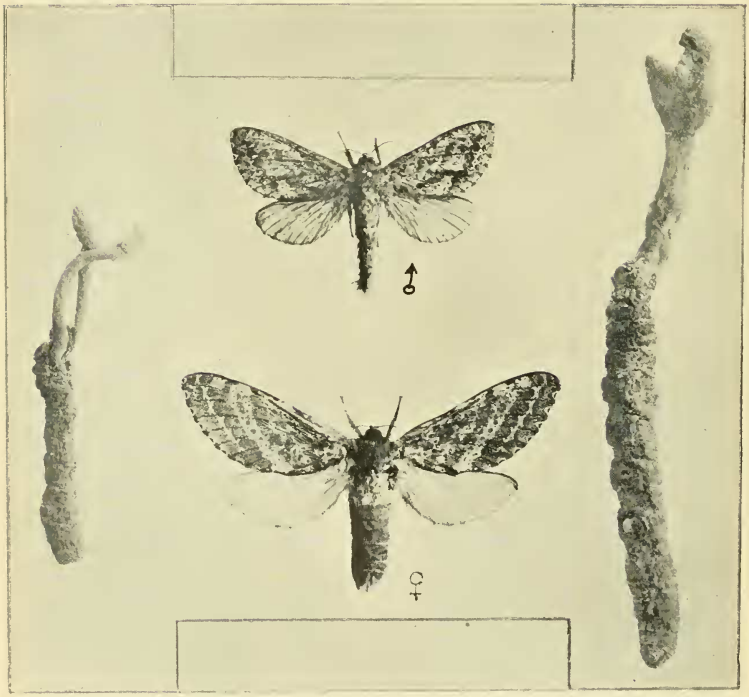
[*E. Bruce Levy, photo.*

Fig. 1.—*Cordyceps Aemonae* Lloyd. × 6. *a*, *c*. Showing characteristic fasciculate growth of stromata. *b*. Isarial form. Arrow points to developing perithecia.

Fig. 2.

Fig. 3. [*E. Bruce Levy, photo.*

Fig. 2.—Larva of *Aemona hirta* Broun, the host of *Cordyceps Aemonae* Lloyd. × 2½.
Fig. 3.—Imago of *Aemona hirta*. × 2½.



[*E. Bruce Levy, photo.*

Fig. 1 Fig. 2 Fig. 3.

Fig. 1.—*Cordyceps consumpta* n. sp. Natural size.
Fig. 2.—*Porina enysii* Butl., the larva of which is the host of *C. Craigii* and *C. Robertsii*. Natural size.
Fig. 3.—*Cordyceps Craigii* Lloyd. Natural size.

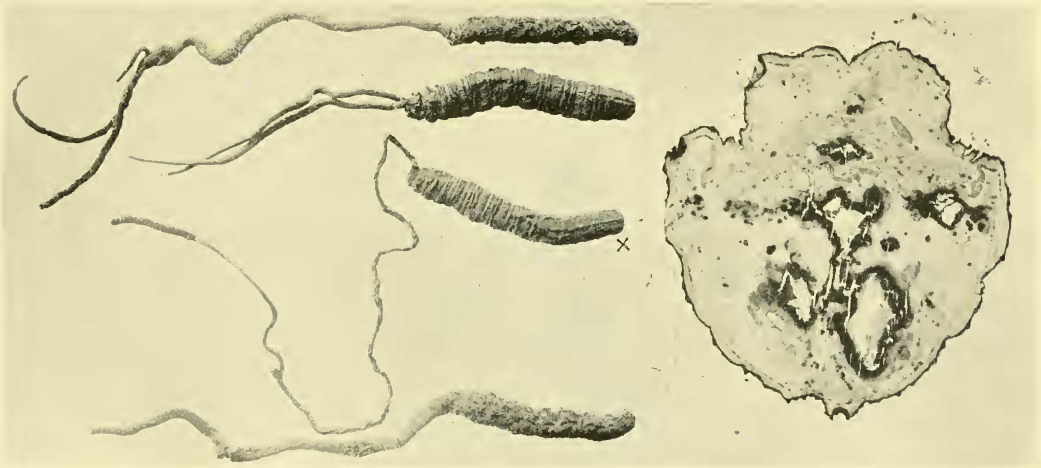


Fig. 1. Fig. 2. [*E. Bruce Levy, photo.*

Fig. 1.—*Cordyceps Robertsii* Hook. Reduced $\frac{1}{2}$.
Fig. 2.—Transverse section through sclerotium; taken from anal portion of specimen marked × in fig. 1. × 10.

[*E. Bruce Levy, photo.*

Fig. 1. Fig. 2. Fig. 3.

Fig. 1.—*Porina dinodes* Meyr., the larva of which, in the South Island, is the host of *C. Robertsii*. Natural size.
Fig. 2.—*Cordyceps Sinclairii* Berk. Specimens from *a* to *d* show gradual development of the stroma; the colour ranges from white in *a*, through yellow in *b*, brown in *c*, to pink in *d*. In *a*, *b*, and *c* the conidia are borne on the tufted apices; in *d* they form a packed mass round the central axis. Reduced $\frac{2}{3}$.
Fig. 3.—*a*. *Melampsalta cruentata* Fabr., the nymphs of which are the hosts of *a* and *d*. *b*. *Melampsalta cingulata* Fabr., the nymphs of which are the hosts of *b* and *c*. Reduced $\frac{2}{3}$.

3. **Cordyceps consumpta**, n. sp. (Plate LX, fig. 1; and text-figs. 3, 4.)

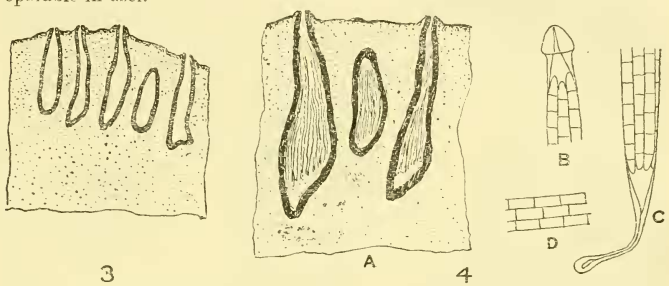
Isarial stage unknown.

Stromata gregarious, two springing from head; 2–3 cm. long; fertile portion cylindrical, curved, apex obtuse, black, 8–10 mm. long, 2–3 mm. thick; rough with projecting necks of the perithecia; sterile portion slender, cylindrical, straight or curved, glabrous, black, 20 mm. long, 1–5 mm. thick.

Perithecia completely immersed, flask-shaped, or more frequently very irregular and distorted; not crowded in the stroma, each perithecium being separated by stromal hyphae; necks protruding; 1,000–1,200 μ long, 200–500 μ wide; necks short; walls 30 μ thick.

Asci hyaline, narrowly cylindrical, tapering slightly towards distal end, markedly towards proximal end, not constricted below capitate apex; 250 × 7 μ.

Spores in parallel fascicles in asci, same thickness throughout, ends bluntly pointed, 180–220 μ; secondary spores 4–5 × 1–1·5 μ, readily separable in asci.



[*Drawn by E. H. Atkinson.*

Cordyceps consumpta.

Fig. 3.—Transverse section through fertile portion of stroma.
Fig. 4.—A. Perithecia (enlarged: note distortion). B. Capitate apex of ascus. C. Base of ascus. D. Secondary spores, 4–5 × 1·5 μ.

Host.—*Porina* sp. (see note); growing from head.

Type Locality.—Rotorua, N.Z., growing from larva buried in soil (A. Lush)!

Distribution.—Known only from type locality.

No. 230, Canterbury Museum collection. (Type.)

In macroscopic characters this species resembles *Cordyceps falcata* Berk., but differs in having the perithecia completely immersed; in *C. falcata* they are perfectly superficial. In microscopic characters there is a strong resemblance to *Cordyceps Craigii* Lloyd; but the difference in perithecial characters, together with the difference in all macroscopic characters, indicates that this is a valid species. It bears a closer resemblance to *C. falcata* and *C. Craigii* than to any other described species.

This specimen, together with many others, was kindly forwarded for examination by Mr. G. Archey, of the Canterbury Museum. It was collected by Mr. A. Lush at Rotorua in June, 1920. Unfortunately, no particulars as to exact locality were appended.

Note on the Host (by J. G. Myers).—The larva infected, unless it be immature, must in this case be that of one of the three smaller common

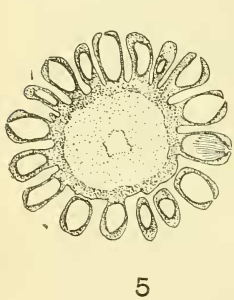
species of the genus *Porina*—namely, *P. cervinata* Walk. (23), *P. signata* Walk. (24), or *P. umbraculata* Guen. (8). At present we have no ascertained constant structural characters by which to distinguish these larvae. The insect is far too small for a larva of *Porina enysii* Butl. (5)—at any rate, for a full-grown one.

4. Cordyceps Robertsii Hook., *Fl. N.Z.*, vol. 2, p. 202, 1855 (emended). (Plate LXI, figs. 1, 2; and text-figs. 5, 6.)

? Sphaeria larvarum Westw., *Proc. Ent. Soc. Lond.*, vol. 2, p. 6, 1836. *Sphaeria Robertsii* Hook., *Icon. Pl.*, vol. 1, t. 11, 1837. *S. Hugelii* Corda, *Icon.*, vol. 4, 44 F, p. 129, 1840. *S. Forbesii* Berk. in *Lond. Jour. Bot.*, vol. 7, p. 578, 1848. *Torrubia Robertsii* Tul., *Sel. Fung. Carp.*, vol. 3, p. 6, t. 1, 1865. *Cordyceps Selkirkii* Olliff in *Ag. Gaz. N.S.W.*, vol. 6. p. 411, 1895 *? C. Coxii* Olliff, *l.c.* *C. larvarum* (Westw.) Olliff, *l.c.*

Isarial stage unknown.

Stroma slender, 10–38 cm. long; fertile portion 6–12 cm. long, 3–4 mm. thick, acute, densely covered with superficial perithecia, which reach to apex of stem; brown, becoming black with age; sterile portion slender, 5–15 cm. long, 2–3 mm. thick, same colour as fertile portion.



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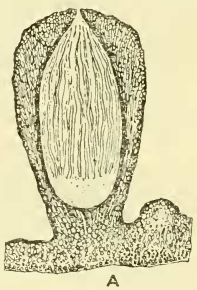

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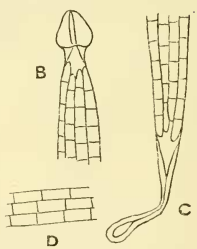

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[*Drawn by E. H. Atkinson.*

Cordyceps Robertsii Hook.

Fig. 5.—Transverse section through fertile portion of stroma.
Fig. 6.—A. Perithecium (enlarged). B. Capitate apex of ascus (note constriction below cap). C. Base of ascus. D. Secondary spores, 5–6 × 3 μ.

Perithecia superficial, small, elongate-obovate or elliptical, densely packed around central axis, easily separable; dark brown, composed of coarse hyphal threads; 600–880 × 300–400 μ; wall thick, 30–50 μ.

Asci hyaline, narrowly cylindrical, tapering slightly towards distal end, markedly towards proximal end, terminating in a long slender pedicel; slightly constricted below capitate apex; 280–400 × 9–10 μ.

Spores in parallel fascicles, filiform, equally thick throughout, bluntly pointed, multiseptate, 280 × 3 μ; secondary spores 5–6 × 3 μ, not readily separable in asci.

Hosts.—*Porina enysii* Butl.; *P. dinodes* Meyr. Growing usually from head, rarely from anal region. (Plate LX, fig. 2; Plate LXII, fig. 1.)

Type Locality.—Given in *Icones Plantarum* as "N.Z."

Distribution.—More or less general throughout the North Island. Specimens have been recorded from the following localities: Rotorua